

# Observations of Soft Gamma Ray Sources $> 100$ keV Using Earth Occultation with GBM

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The NaI and BGO detectors on the Gamma ray Burst Monitor (GBM) on Fermi are now being used for long term monitoring of the hard X-ray/low energy gamma ray sky. Using the Earth occultation technique demonstrated previously by the BATSE instrument on the Compton Gamma Ray Observatory, GBM produces multiband light curves and spectra for known sources and transient outbursts in the 8 keV - 1 MeV band with its NaI detectors and up to 40 MeV with its BGO. Coverage of the entire sky is obtained every two orbits, with sensitivity exceeding that of BATSE at energies below  $\sim 25$  keV and above  $\sim 1.5$  MeV. We describe the technique and present preliminary results after the first  $\sim 17$  months of observations at energies above 100 keV. Seven sources are detected: the Crab, Cyg X-1, Swift J1753.5-0127, 1E 1740-29, Cen A, GRS 1915+105, and the transient source XTE J1752-223.

## I. INTRODUCTION

The Gamma ray Burst Monitor (GBM) on Fermi is currently the only instrument in orbit providing nearly continuous full sky coverage in the hard X-ray/low energy gamma ray energy range. The Earth occultation technique, used very successfully on BATSE, has been adapted to GBM. An initial catalog of 64 sources is currently being monitored and continuously augmented. At energies above 100 keV, six steady sources (the Crab, Cyg X-1, Swift J1753.5-0127, 1E 1740-29, Cen A, GRS 1915+105) and one transient source (XTE J1752-223) have been detected in the first year of observation. We describe the instrument, outline the technique, and present light curves for the seven sources.

## II. GBM AND THE EARTH OCCULTATION OBSERVATIONAL TECHNIQUE

The Gamma ray Burst Monitor is the secondary instrument onboard the Fermi satellite [1, 2]. It con-

sists of 12 NaI detectors  $5''$  in diameter by  $0.5''$  thick mounted on the corners of the spacecraft and oriented such that they view the entire sky not occulted by the Earth. GBM also contains 2 BGO detectors  $5''$  in diameter by  $5''$  thick located on opposite sides of the spacecraft. None of the GBM detectors have direct imaging capability.

Known sources of gamma ray emission can be monitored with non-imaging detectors using the Earth occultation technique, as was successfully demonstrated with BATSE [3, 4]. When a source of gamma rays is occulted by the Earth, the count rate measured by the detector will drop, producing a step-like feature. When the source reappears from behind the Earth's limb, the count rate will increase, producing another step. The diameter of the Earth seen from Fermi is  $\sim 140^\circ$ , so roughly 30% of the sky is occulted by the Earth at any one time. Coupled with the  $\pm 35^\circ$  slewing of the pointing direction every orbit, this means that the entire sky is occulted every two orbits. With an altitude of 565 km, a period of 96 minutes, and an orbital inclination of  $26.5^\circ$ , individual occultation steps last for  $\sim 10$  seconds (Fig. 1).

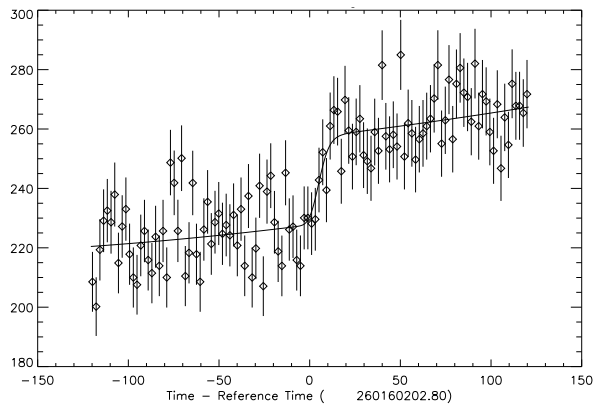


FIG. 1: Single Crab occultation step in a single GBM NaI detector. Horizontal scale is in seconds centered on the occultation time. Vertical scale is in measured counts.

The shape of the individual occultation steps depends on energy and occultation angle. Transmission as a function of time is modeled as  $T(t) = \exp[-\mu(E)A(h)]$ , where  $\mu(E)$  is the mass attenuation coefficient of gamma rays at energy  $E$  in air and  $A(h)$  is the air mass along the line of sight at a given altitude  $h(t)$ . Account is taken of the detector response as it changes as a function of angle across the fit window. For each source, occultation times are predicted. Each step is fit over a 4-minute window along with a quadratic background and using an assumed spectrum to determine the detector count rate due to the source. The instrument response is used to convert the count rate to a flux. Up to 31 steps are possible for a given source in a day, and these steps are summed to get a single daily average flux. The GBM occultation sensitivity exceeds that of BATSE at energies below  $\sim 25$  keV and above  $\sim 1.5$  MeV [5].

This work uses the GBM CTIME data, with its 8 broad energy channels and 0.256-second resolution, rebinned to 2-second resolution. The occultation technique relies on an input catalog of known sources. Currently, we are monitoring 64 sources. Of these 64 sources, 6 steady sources are detected above 100 keV with a significance of at least  $5\sigma$  after  $\sim 490$  days of observations, and one transient source.

### III. RESULTS

The results presented here are preliminary. We have not completed the fine tuning of our algorithms, though the average fluxes are not expected to change much. Future work will include using the GBM CSPEC data, with its finer energy binning, to examine the detailed spectra for these sources.

The measured 20 - 50 keV GBM light curves are compared to Swift's 15 - 50 keV light curves for sev-

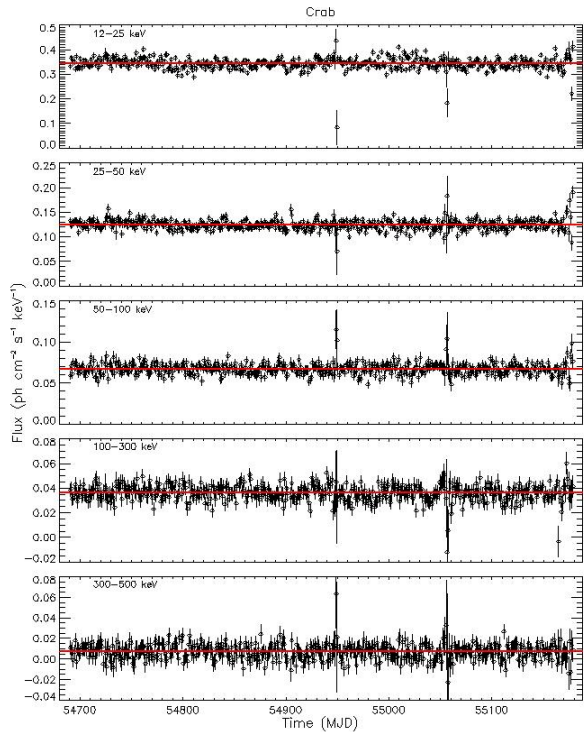


FIG. 2: Crab light curve. Horizontal scale is in modified Julian days over the 490 day GBM exposure period. Vertical scale is in photons/cm<sup>2</sup>/sec/keV averaged over daily intervals. Horizontal lines show the average flux in each of five energy bands increasing from top to bottom

eral sources over the same time intervals in ref. [2], where it is seen that the results measured by the two instruments compare well. At energies above the upper energy limit of  $\sim 195$  keV of the Swift 22-month catalog [6], however, the GBM observations provide the only wide-field monitor available of the low energy gamma ray sky.

#### A. Steady Sources

The sources Crab, Cyg X-1, Swift J1753.5-0127, 1E 1740-29, Cen A, and GRS 1915+105 are detected by GBM at energies above 100 keV. We show GBM light curves generated from the Earth occultation analysis in several energy bands with one day resolution for these six sources in Figures 2 - 7.

Table I gives the fluxes and significances averaged over all the days from Aug. 12, 2008 (the beginning of science operations) to Dec. 15, 2009, approximately 490 days.

The **Crab** (Fig. 2) spectrum in the hard x-ray/low energy gamma-ray region can be described by a broken power law, with the spectrum steepening at 100 keV and then hardening at 650 keV [7, 8]. While the GBM CTIME data do not have the spectral resolution

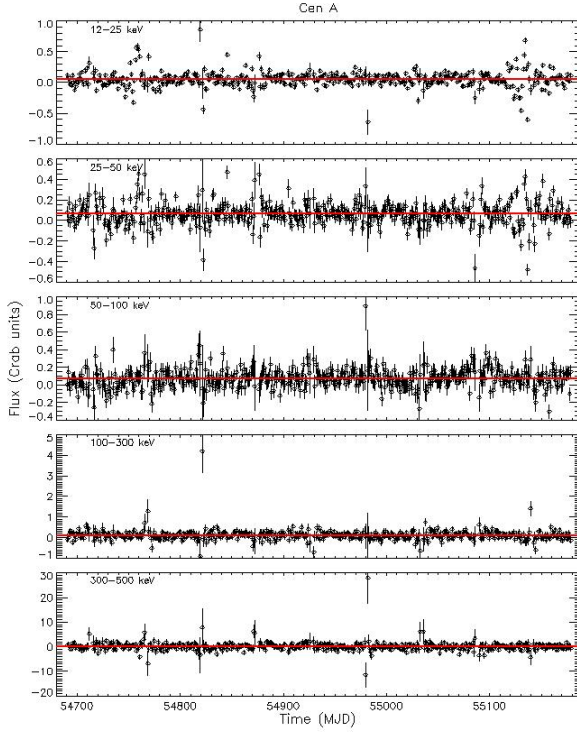


FIG. 3: Cen A light curve. Horizontal scale is in modified Julian days.

to observe these breaks, GBM is able to see significant emission above 300 keV, consistent with the canonical hard spectrum.

**Cen A** (Fig. 3) is a Sy 2 galaxy that is the brightest AGN in hard x-rays/low energy gamma rays. It has a hard spectrum ( $\Gamma = 1.8$ ) and has been observed at energies  $> 1$  MeV [9]. The GBM results are consistent with this hard spectrum, though GBM does not have the sensitivity to determine if the hard spectrum continues beyond 300 keV or if the spectrum cuts off.

**Cyg X-1** (Fig. 4) is a HMXB and one of the first systems determined to contain a black hole. It has been observed to emit significant emission above 100 keV including a power law tail extending out to greater than 1 MeV [10, 11]. The GBM results show significant emission above 300 keV, consistent with the power law tail observed when Cyg X-1 is in its hard state.

**GRS 1915+105** (Fig. 5) is a LMXB with the compact object being a massive black hole. Evidence for emission above 100 keV has been seen previously [12] with BATSE. The GBM light curve integrated over 490 days shows significant emission above 100 keV.

**1E 1740-29** (Fig. 6) is a LMXB very near the Galactic Center. It is a microquasar, and spends most of its time in the low/hard state. Integral observations indicate the presence of a power law tail above 200 keV [13]. The present GBM results are consistent with this high energy emission. In the future, we

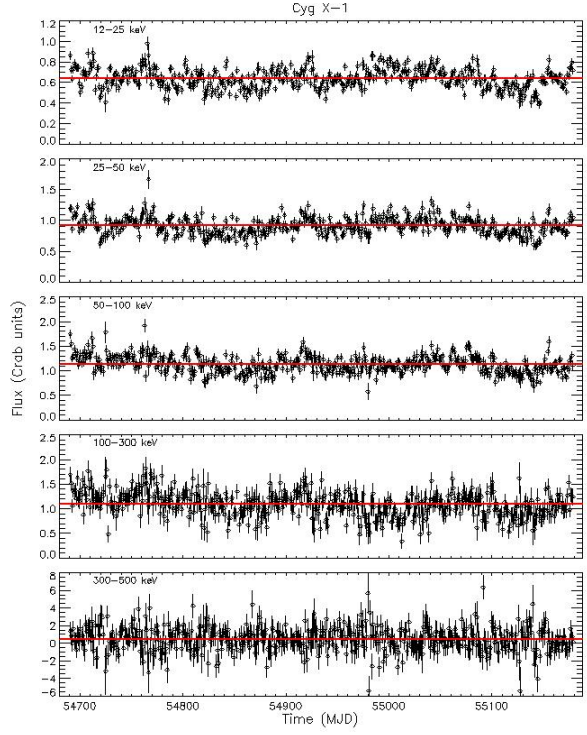


FIG. 4: Cyg X-1 light curve. Horizontal scale is in modified Julian days.

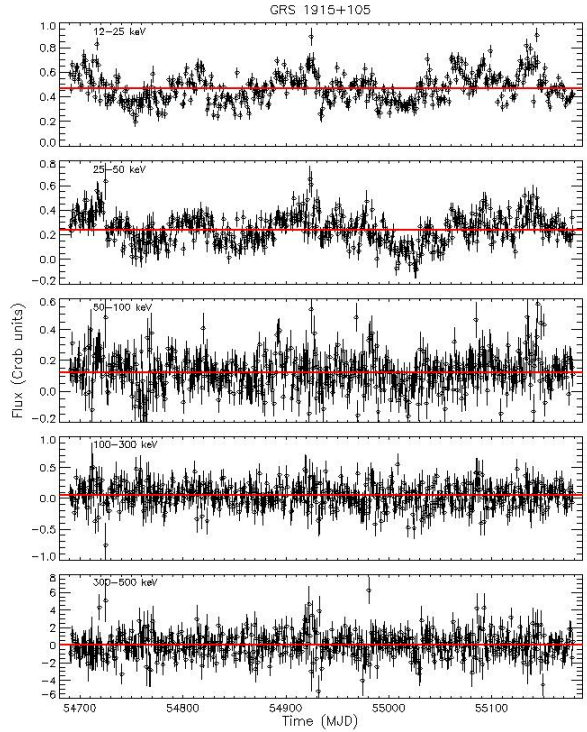


FIG. 5: GRS 1915+105 light curve. Horizontal scale is in modified Julian days.

TABLE I: Fluxes and Significance in High Energy Bands

	50 - 100 keV			100 - 300 keV			300 - 500 keV		
	Flux (mCrab)	Error (mCrab)	Signif. ( $\sigma$ )	Flux (mCrab)	Error (mCrab)	Signif. ( $\sigma$ )	Flux (mCrab)	Error (mCrab)	Signif. ( $\sigma$ )
Crab	1000	3	336	1000	6	182	1000	47	21.2
Cen A	72	4	18	108	7	15	42	47	0.9
Cyg X-1	1130	4	283	1094	8	137	474	50	9.5
GRS 1915+105	121	4	30	49	7	7	41	52	0.8
1E 1740-29	113	5	23	96	10	10	97	68	1.4
SWIFT 1753.5-0127	135	5	27	151	9	17	131	64	2.0
XTE J1752-223	770	16	48	622	30	21	132	218	0.6

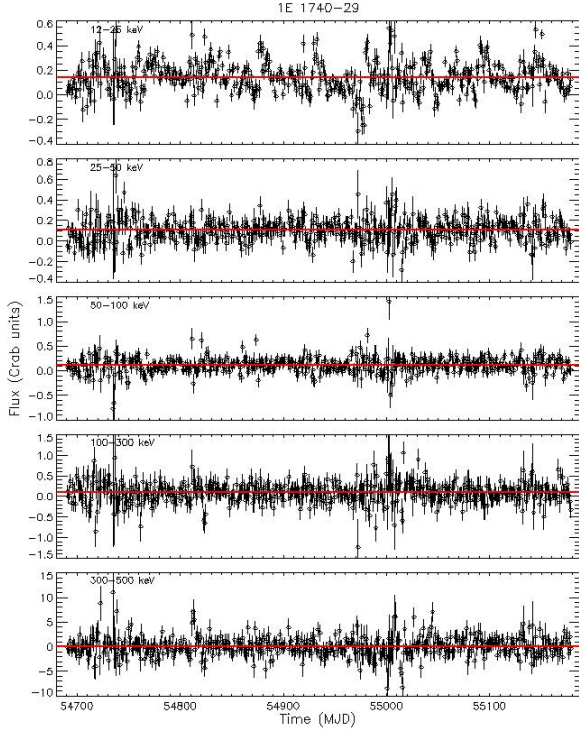


FIG. 6: 1E1740-29 light curve. Horizontal scale is in modified Julian days.

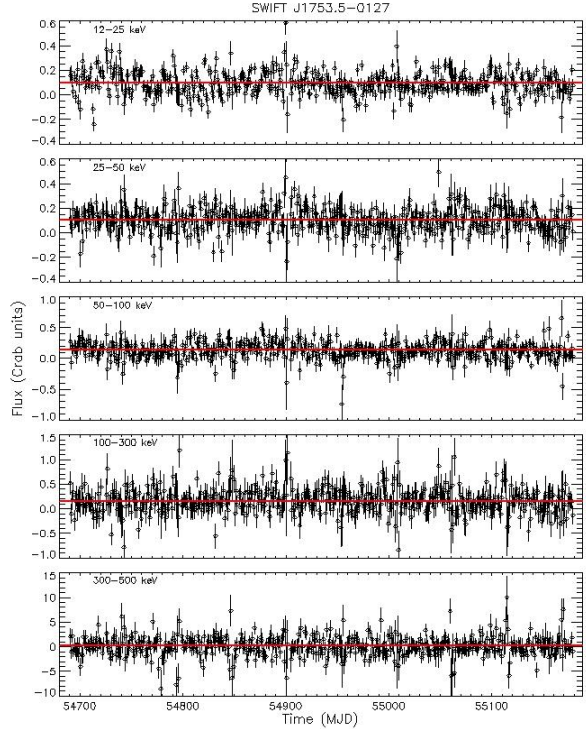


FIG. 7: SWIFTJ1753.5-0127 light curve. Horizontal scale is in modified Julian days.

will use the GBM CSPEC data with their finer energy bins to obtain a fit to the spectrum and compare the power law index to that measured by Integral.

**SWIFT J1753.5-0127** (Fig. 7) is a LMXB with the compact object likely being a black hole. Swift discovered this source when it observed a large flare in July of 2005. The source did not return to quiescence but settled into a low intensity hard state [14]. BATSE occultation measurements from 1991-2000 showed no significant emission from this source above 25 keV [15]. The GBM results show that this source is still in a hard state, with significant emission above 100 keV. We will continue to monitor this

source while it is in the hard state, with longer observations potentially verifying significant emission above 300 keV.

## B. Transient Source

The new transient black hole candidate **XTE J1752-223** rose from undetectable on 2009 October 24 to  $511 \pm 50$  mCrab (12 - 25 keV),  $570 \pm 70$  mCrab (25 - 50 keV),  $970 \pm 100$  mCrab (50 - 100 keV), and  $330 \pm 100$  mCrab (100 - 300 keV) on 2009 November 2 [2, 16]. The light curve is variable, especially in the



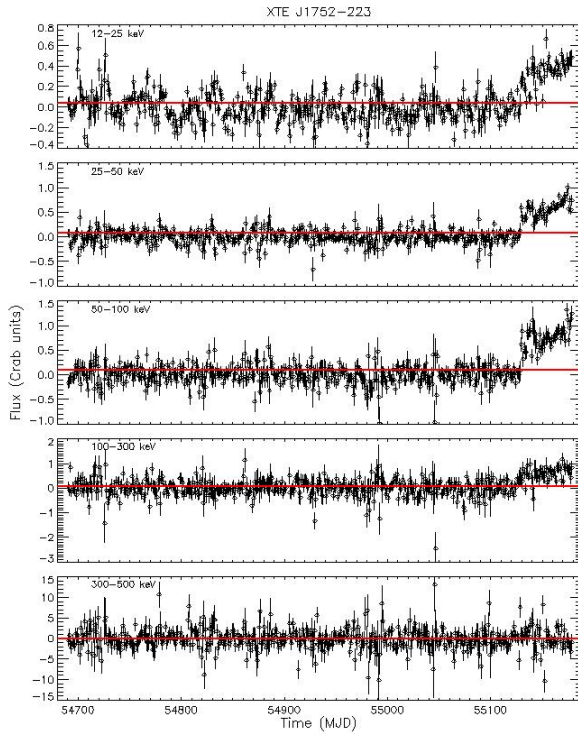


FIG. 8: XTEJ1752-223 light curve. Horizontal scale is in modified Julian days.

12-25 keV band, where the flux initially rose to about 240 mCrab (2009 Oct 25-28), suddenly dropped to non-detectable on 2009 October 29-30, then rose again during the period 2009 October 31 to November 2. As of mid December 2009, the source remains in a high intensity state. The light curve is shown for the period MJD 54700-55200, again with 1-day resolution, in Fig. 8. The fluxes for XTE J1752-223 in Table 1 are given for the interval of flaring activity, TJD 55130-55180.

### Acknowledgments

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